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DAVIDSON LABORATORY

Report R-1137

STEVENS INSTITUTE OF TECHNOLOGY
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HOBOKEN, NEW JERSEY

DRAG STUDIES OF COUPLED AMPHIBIANS

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R.L. Van Dyck
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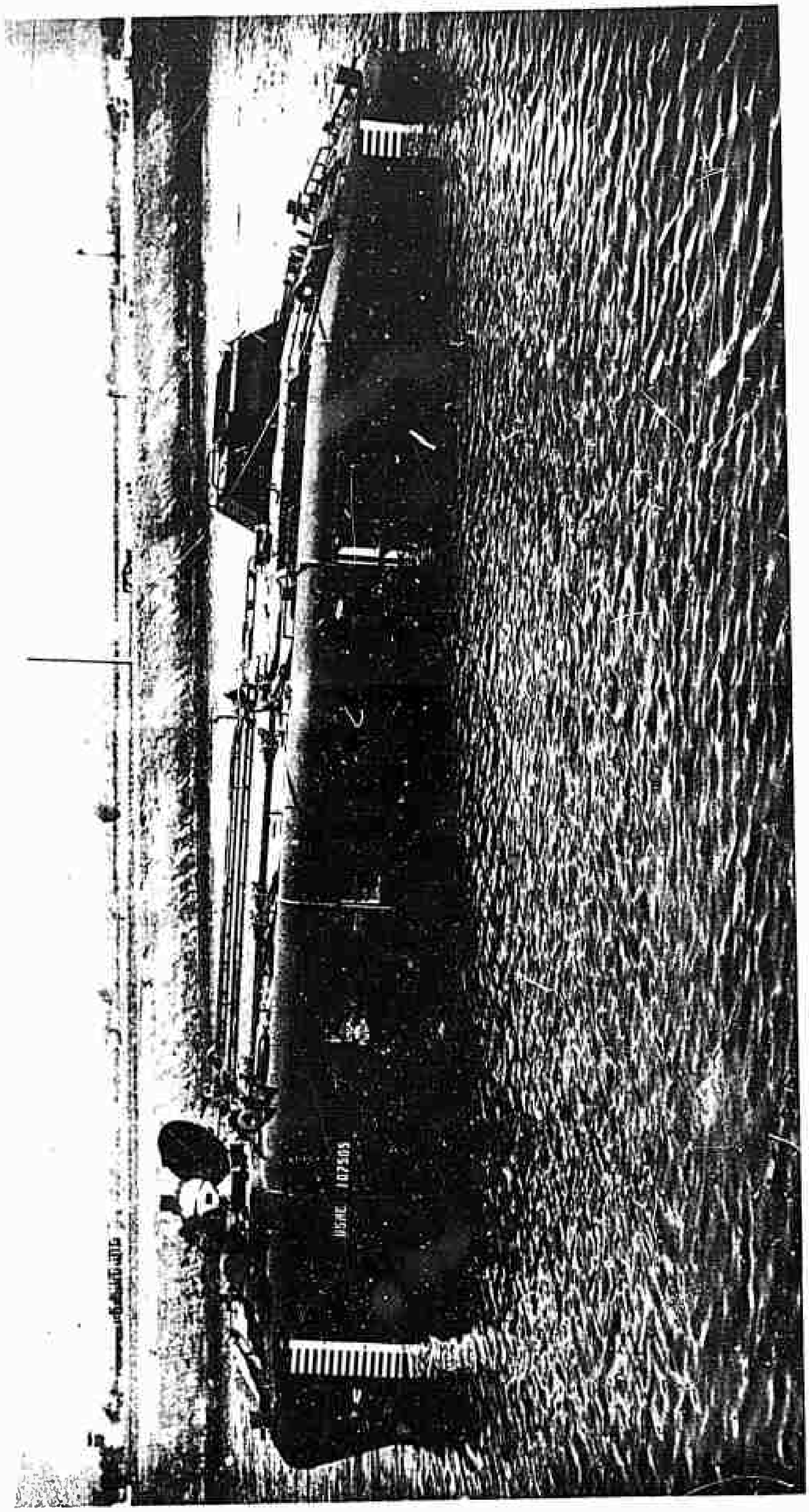

LVTP-5 LYING EMPTY IN WATER

ABSTRACT

This report describes tests conducted to obtain the hydrodynamic drag characteristics of coupled models of the LVTP-5. Problems of swamping and broaching were also studied, and are discussed.

It was found that the total resistance of a train of five vehicles is less than twice the resistance of a single vehicle. If propulsive efficiency is unaffected by coupling, this represents a potential speed gain of almost 50 percent.

KEYWORDS

Amphibians

Vehicular Trains

Mobility

LVTP-5

Swamping

Broaching

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NOMENCLATURE

CG	center-of-gravity location, or fittings 3-in. above model baseline
D	drag force developed, lb
$D_{N=1}$	drag force developed for a single isolated vehicle
ehp	effective horsepower required, $\frac{Dv}{550}$
L	over-all length of vehicle, ft
N	number of vehicles in the train
S	spacing between bow of a vehicle and stern of preceding vehicle, ft
Sta	station distance aft of basic bow forepoint, in.
v	forward velocity, fps
V	forward velocity, mph

SUBSCRIPTS

max	maximum
N (or a numeral)	a train of N (or a certain number of) vehicles
S	a train of the same number of vehicles, with S spacing

DEFINITIONS

Heave	vertical rise (+) or sink (-) of instrumented-model CG (0 at V=0), ft
Trim	pitch angle of instrumented-model baseline, deg; bow-up is positive
Deck	fittings 6.5-in. above model baseline
Fixed	links fixed to fittings at aft end of forward model
Free	links free to pivot in pitch at forward and aft ends

INTRODUCTION

This report presents the results of a model study undertaken to find the gains that can be obtained for the water speed of amphibious vehicles, by coupling them end-to-end to form a train.

During the period 1956-58, the Davidson Laboratory conducted a series of studies for the U. S. Army Ordnance Tank-Automotive Command, aimed at improving the water speed of various amphibious vehicles.[1] Due to the limited mission of the supporting agency, these studies were restricted to a consideration of wheeled amphibious vehicles. Under the program, a great many studies and tests were conducted; attempts were made to improve water speed by changes, additions, or deletions to the hull shape and other submerged components. The results, in general, were disillusioning. Those changes which produced a significant improvement proved to be generally unacceptable for land off-road use. A novel concept, however, which promised significant improvement without many corresponding disadvantages, was that of the SEA SERPENT, a multi-vehicle train. Preliminary tests conducted at that time indicated that the hydrodynamic drag of eight vehicles coupled together was such that the speed of the coupled configuration would be double that of a single vehicle, if the ehp/unit remained constant.

Subsequent to the SEA SERPENT tests, the Davidson Laboratory was involved in a number of studies associated with land-vehicle performance. Some of these centered about tests in which a number of cross-country vehicles were coupled together in the form of a land train. A significant number of mobility and operational advantages were demonstrated in these studies. For example, obstacles which a single vehicle could not pass, such as ditches and the "twilight zone" (water-land transition), were found to be surmounted easily by a train of vehicles coupled together. Therefore it looked practical — from both a water-borne and land-borne viewpoint — to investigate the concept of vehicle trains for amphibious operations.

The tests conducted in this study were designed to investigate the drag-speed characteristics of the LVTP-5 amphibian in various grouping arrangements, spacings, and loadings. A limited study of directional behavior in waves was also conducted, as a check on possible broaching characteristics.

MODEL DESCRIPTION

Five identical 1/12-scale, unpowered, fiber-glass hull models of the LVTP-5 were fitted with stationary wood and aluminum tracks (Fig. 1). These models were ballasted to simulate both combat-loaded (82,500 lb) and empty (70,500 lb) weights.[a] Since superstructure configuration has no effect on water performance, except during swamping, a smooth, unobstructed deck was used. The models were equipped with simple pin-connection fittings so that they could be linked together in tandem, with yaw restraint. Different link lengths provided variations in vehicle-to-vehicle spacing.

Full-scale thrust moment was simulated by ballasting the models to the pitch-angle change (for full power at maximum speed) obtained by the FMC Corporation during prototype tests conducted at Camp Pendleton.[3] On two models, both deck- and CG-height pin connections were fitted to make possible a determination of the effect of towing moment on drag and trim when deck-height towing is used instead of CG-height towing, with zero moment. The remainder of the multiple-vehicle tests were conducted with deck-height fittings and with 1/4-inch tubular brass links for connections between models. Ballasting was used to apply the thrust moment to every vehicle in the train. In every configuration but one, the towing-tank carriage pulled the front model at its combat-loaded CG. Models behind the front model were propelled by the pin-connection fittings which linked the vehicles. For one configuration, the trailing vehicle of a two-unit train was towed (Table 1, p. 6).

Models were ballasted to simulate both empty (70,500 lb) and fully combat-loaded (82,500 lb) weights. Static combat-loaded water line was obtained from vehicle drawings (Fig. 1). Since all personnel and equipment are carried in the forward section of the vehicle, the empty condition results in a 49,600-ft-lb bow-up moment about the combat-loaded CG, as well as removal of 12,000 lb of weight.

APPARATUS AND PROCEDURE

The drag tests were conducted at constant speed in the Davidson Laboratory's Tank 3. A precision drag balance of 10-lb capacity was used, in conjunction with the standard Schaevitz trim-angle and heave transducers, for measurement of resistance, trim angle, and heave of the CG of the propelling vehicle.[4] In the photographs (Figs. 2, 3, and 4), the models are shown set up in the free-to-heave apparatus, which also permits freedom-to-trim at fixed yaw and roll angles. The calibrated signals from the transducers were transmitted by overhead cables to the standard recording equipment on shore. Speed was measured by timing the model over a 20-foot section of tank while data were being recorded. Constant loading was applied to each model to ballast it to the correct floating water line for the full 82,500-lb combat load (indicated in Figure 1 by stars and the line joining them; see, also, Figure 2). Trial runs were then made with various fixed applied pitching moments, to cover the desired range of running trim angles.

Currently, a 4-degree trim angle is achieved on the prototype at 6.7 mph for empty weight operation,[3] about a $1\frac{1}{4}$-degree increase over the trim angle for static floating conditions. The 46,600-ft-lb bow-up moment required to achieve this extra $1\frac{1}{4}$-degree trim was then applied to both the empty (70,500 lb) and combat-loaded (82,500 lb) conditions during all subsequent model-test comparisons.

Each test configuration was run at various velocities up to the swamping speed. At this point the bow of the lead vehicle was overrun by its bow wave (Fig. 2f). In some multiple tests, 20 inches (full scale) of additional freeboard was added by a bow shield, permitting higher speeds prior to swamping (Fig. 3). In addition, for some of the five vehicle trains, additional freeboard was obtained by operating the lead vehicle under empty conditions.

Table 1 lists the various configurations tested for hydrodynamic drag.

Tests to investigate the broaching tendency in following waves were carried out, with a quick-release clamp on the "nutcracker" free-to-heave apparatus. This device took the train up to the maximum operating speed (6.8 mph)[b] at zero yaw angle, and released it at the proper location in the tank. Once the train was released, it was allowed to drift entirely free of any restraint, throughout its run. Color motion pictures were taken, looking toward the approaching waves from the initial release point through approximately the first 30 feet of the model run. Both single- and multiple-vehicle configurations were tested in regular following seas of various lengths and heights up to breaking waves; prototype-scale heights ranged from 4 to 10.5 feet (at breaking) and lengths of 144 and 84 feet. In addition, a single vehicle was set at several other headings relative to the waves and released to float freely under the action of the waves at zero speed. These zero-speed tests were made in an attempt to find an unstable broaching-type condition for a single LVTP-5 floating at any heading to the waves. Motion pictures were also taken of these static tests.

TABLE 1

DRAG-TEST CONFIGURATIONS OF LVTP-5 TRAINS

Configuration No.	Configuration
1	[T]
2	[T] [ ]
3	[T] [ ]-[ ]
4	[T] [ ]-[ ]-[ ]-[ ]
5	[T]-[X]
6	[T]-[X] [ ]
7	[T]-[X] [ ]-[ ]-[ ]
8	[T]-[X]-[X]
9	[T]-[X]-[X] [ ]
10	[T]-[X]-[X] [ ]-[ ]
11	[T]-[X]-[X]-[X]
12	[T]-[X]-[X]-[X] [ ]
13	[T]-[X]-[X]-[X]-[X]
14	[X]-[T]

Legend:

- [T] Instrumented towing vehicle
- [X] Vehicles supported by instrumented tow strut
- [ ] Vehicles supported by uninstrumented tow strut

DISCUSSION OF RESULTS

EFFECTS OF SPEED ON SWAMPING

Figure 2 shows the effects of speed on the build-up of the bow wave — the principal cause of drag and, ultimately, swamping, as speed is increased. A large trough is formed at each side just aft of the bow, in the vicinity of the front end of the tracks. This trough becomes deeper and the side wave becomes longer as speed is increased, until swamping of the bow occurs; then the trough is filled in with some of the flow over the bow.

Figure 3 shows that the bow wave for the lead vehicle is formed in the same manner, regardless of the number of vehicles coupled behind it. However, there is practically no side wave on all the trailing vehicles, until speeds near 10 mph are reached. It should be noted that no bow wave is formed by any but the lead vehicle; this was found to be true irrespective of the number of vehicles coupled together in the train.

Figure 4 shows the effects of the addition of freeboard at the bow. The swamping tendency appears to be independent of the number of vehicles in the train. Additional freeboard would therefore be necessary to obtain increased speed by the use of the techniques described in this report. For achieving additional freeboard in varying amounts and with varying degrees of success, several techniques are illustrated. The figure shows that the addition of a bow-up moment — equivalent to a rearward shift in load — tends to alleviate swamping, as does the lightening of the load. The empty load condition, with its more aft CG location, delays swamping until a speed of over 9 mph is reached. However, since it is essential that these vehicles operate at their full combat load, some auxiliary device be employed to add freeboard directly. Figures 2 and 14 show that swamping with the bare hull occurs at about 7.1 mph. Twelve inches of additional freeboard delays swamping until a speed of 7.6 mph is

reached. A 20-inch freeboard-shield allows speeds in excess of 8.3 mph. Under empty conditions, a 20-inch shield would allow speeds of over 10 mph.

EFFECTS OF THRUST MOMENT

Calm-water drag tests of a single LVTP-5 model were conducted to investigate the effects of applied bow-up pitching moment on drag. The results of the applied-moment tests are plotted in Figures 5 and 6. It should be noted that these plots are for constant applied moment over the entire speed range. But in the prototype vehicle the track thrust line is below the CG; hence the bow-up moment will increase with increasing speed up to the calculated value of 46,600 ft-lb at maximum speed (6.8 mph). These two figures show that drag appears to be unaffected by trim changes due to moment variation. The addition of a bow shield, however, which delays the onset of swamping, materially decreases the drag at speeds where the bare-hull models swamp.

Because drag was found to be insensitive to trim angle, only the 46,600-ft-lb equivalent to full-thrust moment was applied to each vehicle and maintained during all subsequent testing at all speeds. This lack of apparent effect on drag with sometimes varying trim angle occurs because the pressure drag is by far the major source of resistance, and because the friction drag, which varies with changes in wetted area, is small (on the order of 5 percent of the total drag) — in the range of operating speeds and Froude numbers of the LVTP-5 amphibian.

EFFECTS OF LOADING

Comparison of Figure 5 with Figure 6 shows that changes in drag resulting from different hull-loadings are small, though not negligible. At 6.8 mph, the removal of 12,000 lb of load ($14\frac{1}{2}$ percent) produces a drag reduction of about 6 percent.

As mentioned earlier, in the discussion on swamping, additional freeboard under empty conditions delays the onset of swamping of the bare hull; instead of occurring at 7.1 mph, it occurs at over 9 mph.

EFFECTS OF SPACING

Figure 7 shows that there is a change in drag with inter-vehicle spacing. For two vehicles in tandem, a decrease in spacing from 6 feet to 1 foot produces a 15-percent decrease in drag at 6 mph. Figure 8 is a plot of the complete range of possible spacings of two vehicles in tandem at 7 mph. The right-most point represents the combined drag of two infinitely spaced vehicles (twice the ehp of a single isolated vehicle). It is clear, therefore, that a minimum spacing is advantageous, but that little gain is obtained by reducing the spacing to less than 1 foot.

The results which are presented here were developed for only two vehicles in tandem. It is felt that, in general, they apply to a train of any length. Therefore all subsequent multiple-vehicle tests were conducted at zero spacing (Fig. 3).

EFFECTS OF CONNECTING-LINK CHANGES

It was believed that the pitch moment caused by the forces exerted by the interconnecting links might change the vehicle's trim and, perhaps, its drag characteristics. Two connection heights were therefore installed on each model (Fig. 1). One was at the approximate height of the vehicle CG when the vehicle stands on level ground; the other was 3.5-feet (full scale) higher, at approximately the same height as the major portion of the top deck. Figure 9 shows that these variations produced no measurable change in heave, trim, or ehp, for two vehicles in tandem.

It was also important to learn whether or not the type of linkage connection affected vehicle performance. Figure 10 shows that fixing the link at the forward of two vehicles in tandem had a marked effect on vehicle trim. The heave and ehp, however, changed negligibly. This fact is not surprising in view of the data presented in Figures 5 and 6.

EFFECT OF PROPELLING-VEHICLE LOCATION

Here again, interconnecting forces could, perhaps, change vehicle characteristics. Figure 11 shows that the ehp remains constant regardless

of whether the first or last of a two-unit train is the towed vehicle. The tests in which the front vehicle was towed are therefore also valid for prototype analysis, where each vehicle is self-propelled.

DISCUSSION OF TOTAL AND AVERAGE EHP REQUIRED

Figure 12 shows the modest increases in ehp at a given speed, as vehicles are added to the train. It also shows how much increase in speed may be achieved by trains of two and three vehicles when a fixed ehp per vehicle is assumed. Similar increases in speed can be expected of self-propelled prototypes if the individual propulsive efficiency of each unit is not degraded by interaction between units in a train — a reasonable assumption, but unsubstantiated because of lack of data.

The average ehp per unit required to maintain 7 mph is plotted in Figure 13. This figure indicates that, although the curve is beginning to level off, additional gains may be obtained bv coupling vehicles into trains of more than five vehicles, providing operational problems do not develop.

Figure 14 has been prepared to show the effect of coupling additional vehicles on the estimated top speed possible for a train, when equal propulsive efficiency is assumed for each vehicle added. This figure is speculative in that it assumes equal increments of available thrust horsepower for each vehicle added to the train and is based on the simplified non-propulsive track-model drag-horsepower curves of Figure 12. The drag-horsepower curve for five vehicles was extended up to high speed by arbitrarily lightening the load to empty weight on the lead vehicle with 20-inch freeboard, thus delaying swamping to the 10.2-mph speed limit line shown. The available power, however, would appear to limit the top speed for five vehicles to about 9.2 mph. Insufficient freeboard was available to enable four models to reach the estimated interpolated top speed of about 8.9 mph, so no test point is shown here. Varying amounts of freeboard tested for the lead vehicle provided the swamping speed limit lines shown at 7.1, 7.6, 8.4, and 10.2 mph (with empty weight).

DRAG BREAKDOWN FOR EACH VEHICLE

In order to determine the drag experienced by each vehicle in the train, instrumented towing struts were inserted at different locations (Table 1). Table 2 shows how the results of these tests were used to calculate the drag on each unit.

The results of this analysis for speeds near 7 mph are presented in Figure 15. Note that the incremental increase of the ratio $D/D_{N=1}$ appears to remain constant with increasing N. The first vehicle appears to contribute the same drag for all train configurations where $N \geq 2$. This fact appears to be true, also, for the second vehicle where $N \geq 3$, the third vehicle where $N \geq 4$, and the last vehicle where $N \geq 2$.

In the train configuration, the first vehicle experiences approximately 75 percent of the drag of a single vehicle; the last vehicle experiences approximately 50 percent of the drag of a single vehicle; and the interior vehicles experience between 20 and 25 percent of the drag of a single vehicle.

As would be expected, Figure 15 shows that most of the drag in a train of vehicles is developed by the first and the last vehicles. The middle vehicles contribute very little. Figure 15 also reveals that the total resistance of a train is essentially a linear function of the total number of units in the train.

TABLE 2

METHOD OF COMBINING TEST DATA TO OBTAIN DRAG OF EACH MODEL

Number of Models In Train	Sequence Number of Model	Test Numbers (see Table 1)
1	1	1
2	1	2
2	2	5-2
3	1	3
3	2	6-3
3	3	8-6
4	1	equivalent to 4
4	2	equivalent to 7-4
4	3	equivalent to 10-7
4	4	11-9
5	1	4
5	2	7-4
5	3	10-7
5	4	12-10
5	5	13-12
1	1	1
2	1+2	5 or 14
3	1+2+3	8
4	1+2+3+4	11
5	1+2+3+4+5	13

DIRECTIONAL BEHAVIOR IN WAVES

It is generally considered that steep, following waves will develop the worst conditions for broaching and directional stability.

Table 3 outlines the results of the broaching tests. In addition, a 15-minute 16-mm color motion picture was made to summarize these tests and depict the directional behavior of various test configurations. This film has been submitted to the Office of Naval Research as a supplement to this report.

Table 3 and the supplemental motion picture reveal that the single model launched from the carriage at approximately 7 mph (full scale) and allowed to run free in following waves of various lengths and heights up to breaking waves (10.5 ft, full scale) was inherently quite stable and resistant to broaching. Moreover, the train combinations of different numbers of vehicles tested appeared to be equally stable.

It should be noted that the added complexity of a beach was not present in these tests, nor could the semi-rigid (in all but pitch) model fittings have taken the loads that could develop if one of these heavily loaded vehicles were to strike a solid object, such as a beach.

During Run No. 14, in extremely steep 8:1 breaking waves, the fittings were broken from the aft deck of the second model, thereby changing a train of four vehicles into two trains of two vehicles. This occurred only because the hulls tried to pitch to an angle greater than the 25 degrees found permissible with the fittings on the two hulls that separated. The other hull fittings were found to permit several more degrees of relative pitch and, as a result, did not break. The observed performance of the models in waves indicated that full-scale interconnection of LVTP-5 vehicles must be capable of absorbing some degree of shock, if wave or surf operation is contemplated.

TABLE 3

DIRECTIONAL BEHAVIOR IN WAVES AT COMBAT LOAD

(Full-Scale Values at Full-Thrust Moment and Zero Spacing)

Run No.	Units in Train	Added Freeb'd (in.)	Wave Size Ht. x Lgth. (ft)	Release Speed (mph)	Release Heading From Fol. Sea (deg)	Comments
1	1	0	4 x 144	6.8	0	Stable (slowed quickly)
2	1	0	4 x 144	6.8	0	Stable
3	2	0	4 x 144	6.8	0	Stable
4	3	0	4 x 144	6.8	0	Stable (swamping of No. 1 at release)
5	4	20	4 x 144	6.8	0	Stable
6	4	20	4 x 144	7.9	0	Stable (water to top of bow shield)
7	4	20	4 x 144	7.9	0	Stable (check run at this release speed)
8	1	0	7.5 x 157	6.8	0	Stable (some water on bow at release)
9	1	0	8 x 144	6.8	0	Stable (check run for wave size)
10	1	0	8 x 144	6.8	0	Stable (check run, released in trough)
11	1	0	10.5 x 84	6.8	0	Stable (some waves break to 8.5 x 84 ft)
12	1	0	10.5 x 84	6.8	0	Stable (check run for picture)
13	2	0	10.5 x 84	6.8	0	Stable (no picture)
14	4	20	10.5 x 84	6.8	0	Stable (fittings broke between 2d and 3d models)
15	2	20	10.5 x 84	7.9	0	Stable
16	2	20	10.5 x 84	7.9	0	Stable (No. 1 at empty load; No. 2 combat-loaded)
17	1	0	10.5 x 84	6.8	0	Stable (at empty load condition)
18	1	0	10.5 x 84	0	30	Combat-loaded (turned to and stayed at following sea, 0°)
19	1	0	10.5 x 84	0	60	Combat-loaded (turned to and stayed at following sea, 0°)
20	1	0	10.5 x 84	0	110	Combat-loaded (turned to and stayed at beam sea, 90°)
21	1	0	10.5 x 84	0	180	Combat-loaded (stayed at head sea, 180°)

CONCLUSIONS

1. Resistance tests have shown that the coupling of LVTP-5 amphibians end-to-end will materially reduce the ehp/vehicle required to attain any given speed.
2. Additional bow freeboard or modification of hull design is required to prevent swamping and thus enable the LVTP-5 to go faster than 7 mph under combat-loaded conditions. Such changes are essential in order to realize the benefit of reduced ehp/vehicle made possible by coupling.
3. Minimum spacing between vehicles is optimum for all train configurations. Negligible gain is accomplished by reducing the spacing to less than one foot. In general, a S/L of less than 0.2 should be considered adequate.
4. The drag of each vehicle appears to be unaffected by changes in trim, except under those conditions where swamping occurs.
5. Changes in hull loadings in the neighborhood of full load produce only small, but not negligible, changes in hull drag.
6. The position and arrangement of inter-vehicular connecting linkages appear to have no effect on total ehp required. Some changes in trim and heave, however, were observed.
7. Broaching was not observed with either the single vehicle or the train configuration, running in following seas.

RECOMMENDATIONS

1. Full-scale prototype tests should be conducted on various numbers of LVTP-5 vehicles, connected together, to determ   if the speed increase suggested by this program can be realized.
2. If the speed increases are not realized, studies should be instituted to determine what interference effects of vehicular coupling are detrimental to propulsive efficiency.
3. Bow shields and/or modifications in hull design should be developed so that, if the increased speeds are realized, the vehicles will be capable of achieving them under full, combat-loaded conditions, without swamping.
4. Operational problems associated with the coupling of vehicles should be investigated. This investigation should include, but not be limited to, the tactical aspects of coupled operations, the problems of coupling at sea, the problems of steering when coupling is employed, the problems of coupled vehicles in surf, and the subsequent release for freedom to yaw that is necessary for land operations.

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3. Letter from Mr. A. T. Byrne of FMC Corporation to Dr. I. Robert Ehrlich of the Davidson Laboratory, dated 17 February 1965; file NObs 4723-ENG-2417, with enclosures.

4. Davidson Laboratory Annual Report, 1964.

5. Characteristic Sheet Code 529V, entitled "LVTP-5," dated 20 September 1961.

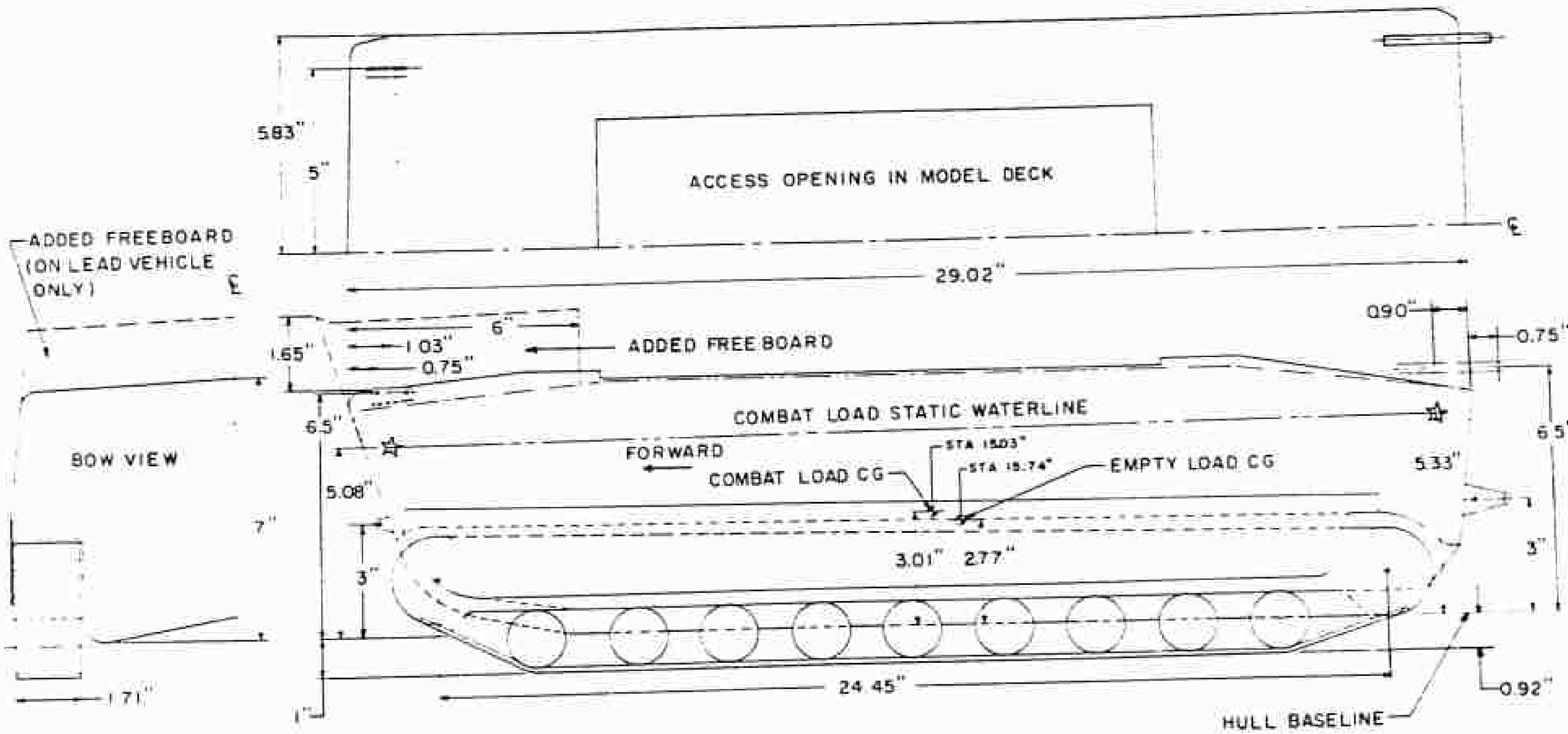
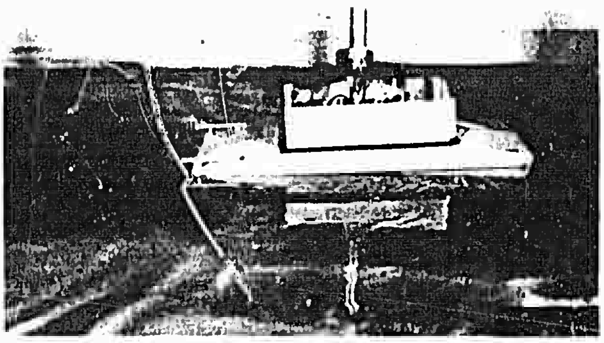
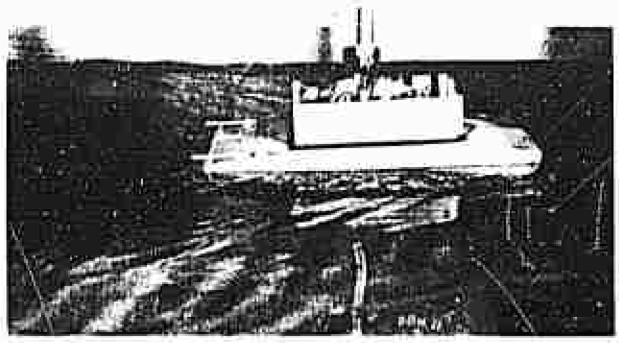


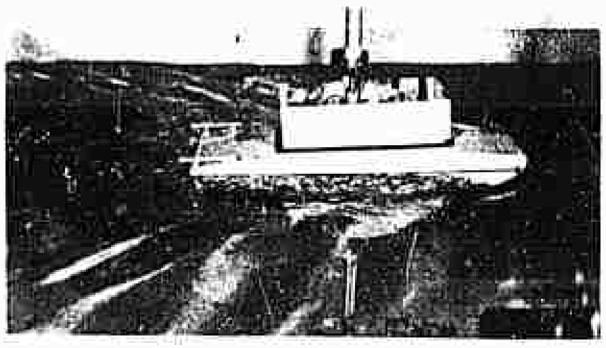
FIGURE I. 1/12-SCALE MODEL LINE DRAWING



(a) V= 2.4 MPH



(b) V= 3.6 MPH



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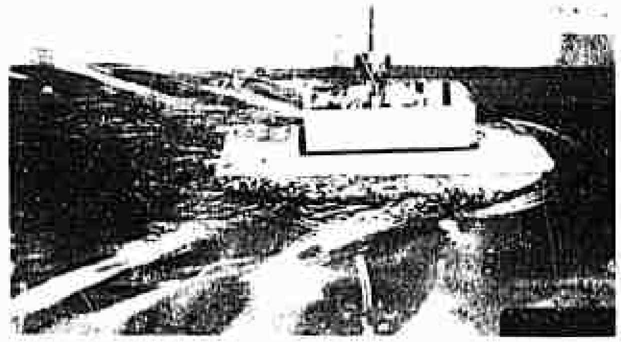
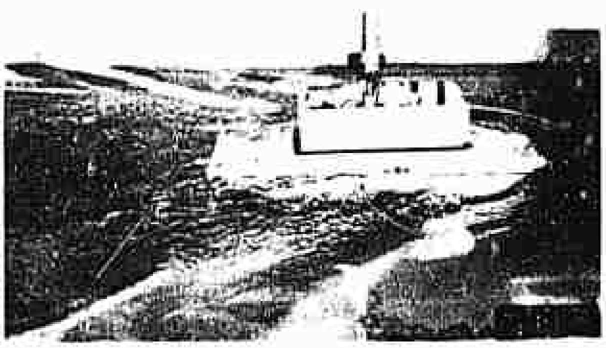


(d) V= 5.9 MPH



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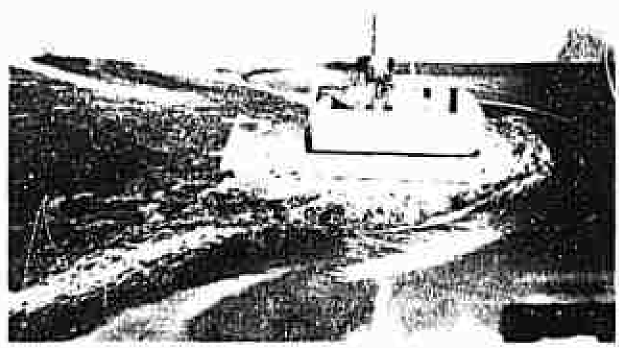
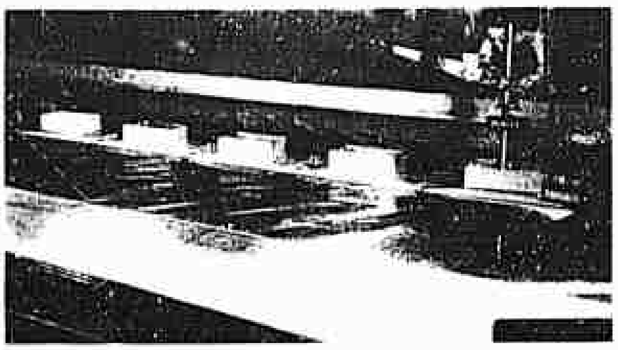


(f) V= 8.3 MPH

FIGURE 2. TESTS OF A 1/12 SCALE, LVTP-5 MODEL UNDER VARIOUS SPEEDS, COMBAT LOADED



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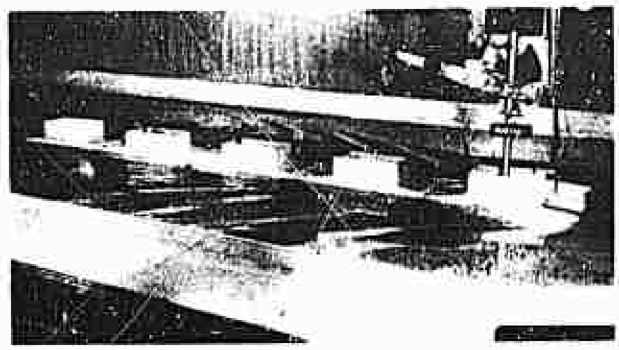

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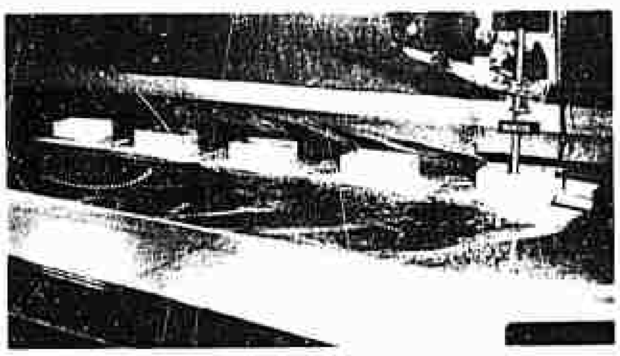
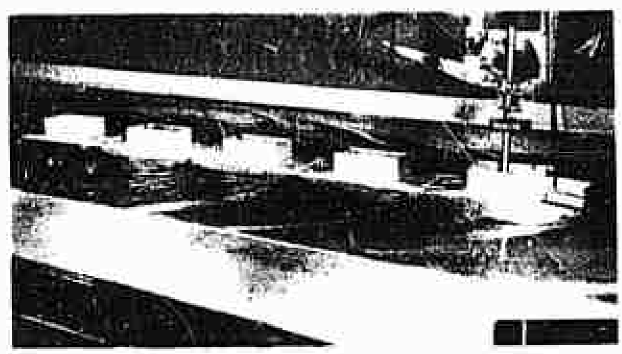
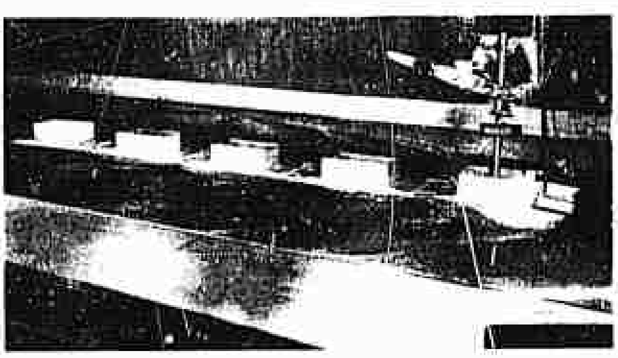


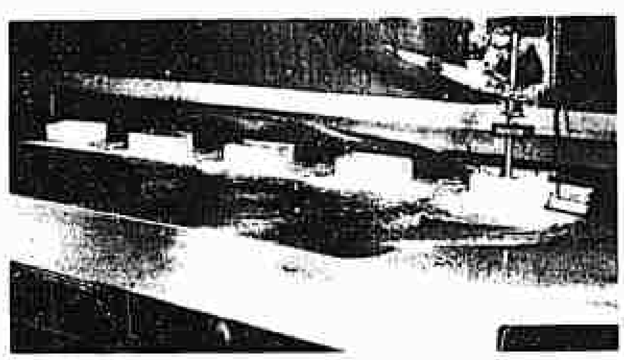
(c) V= 8.3 MPH



(d) V= 9.0 MPH

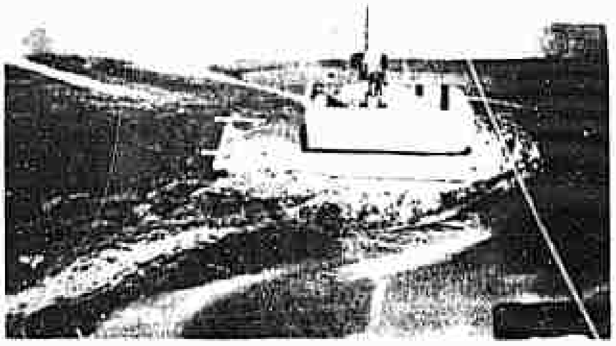


(e) V= 9.6 MPH



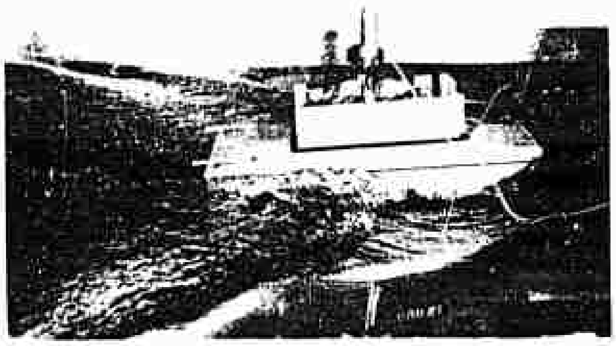
(f) V= 10.2 MPH

FIGURE 3. TESTS OF A FIVE-UNIT TRAIN OF LVTP-5 MODELS, LEAD VEHICLE EMPTY WITH ADDED 20 INCH FREEBOARD, ALL OTHER VEHICLES COMBAT LOADED

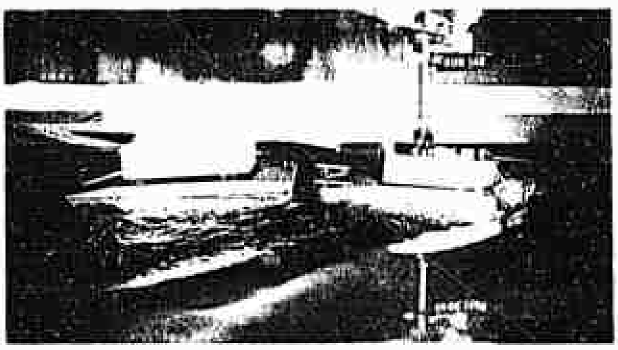


(a) BARE HULL, COMBAT LOADED

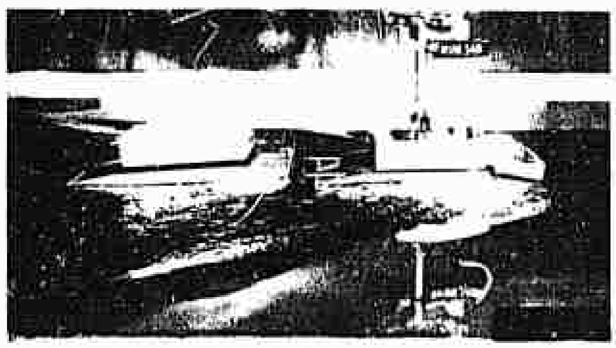
(b) BARE HULL COMBAT LOADED, WITH C.G. SHIFTED 0.5 FT AFT



(c) BARE HULL, EMPTY



(d) HULL WITH 12 IN. ADDED FREEBOARD, COMBAT LOADED



(e) HULL WITH 20 IN. ADDED FREEBOARD, COMBAT LOADED

FIGURE 4. EFFECT OF BOW FREEBOARD ON SWAMPING $V \sim 8.3$ MPH

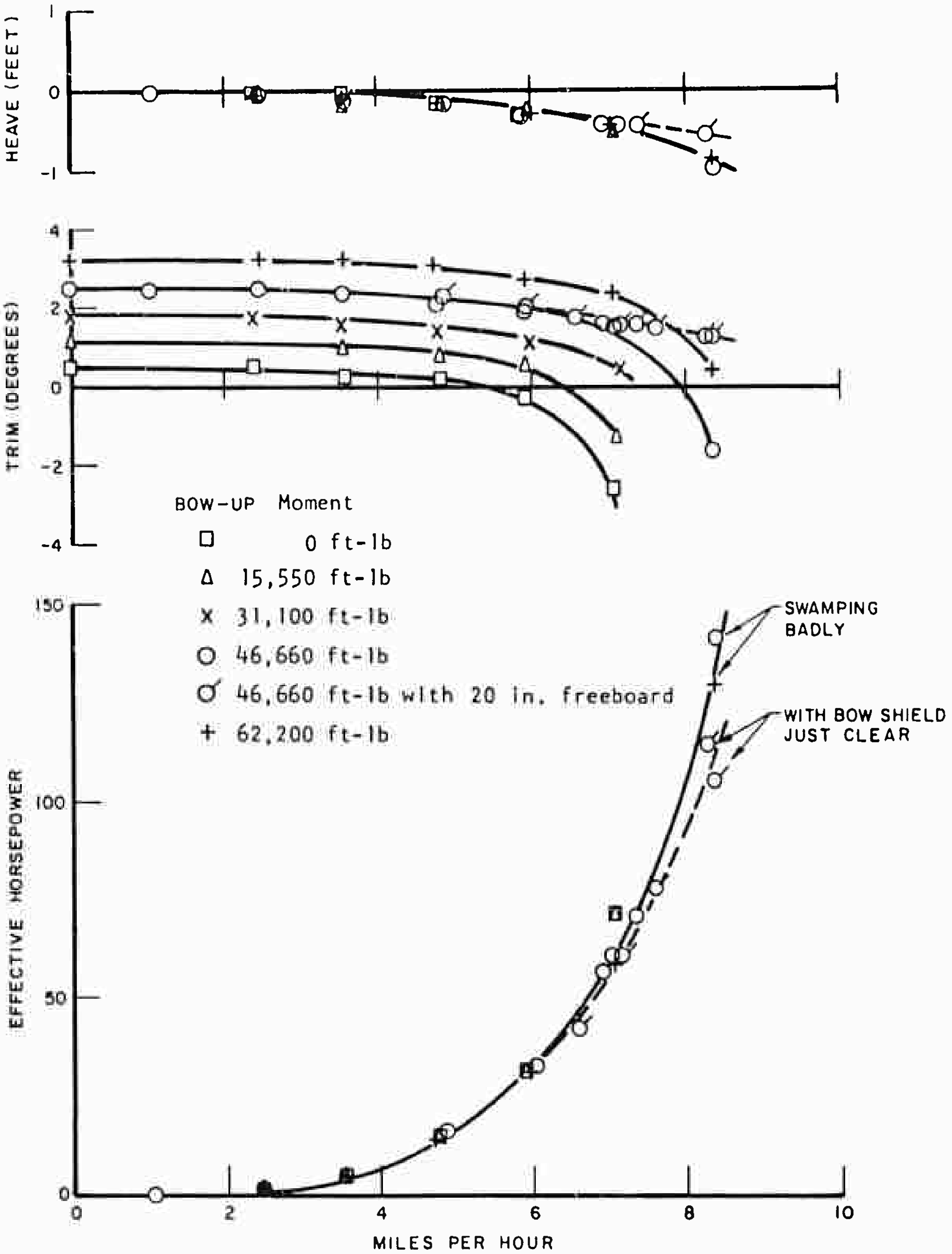


FIGURE 5. EFFECTS OF APPLIED MOMENT AT COMBAT-LOADED CONDITION

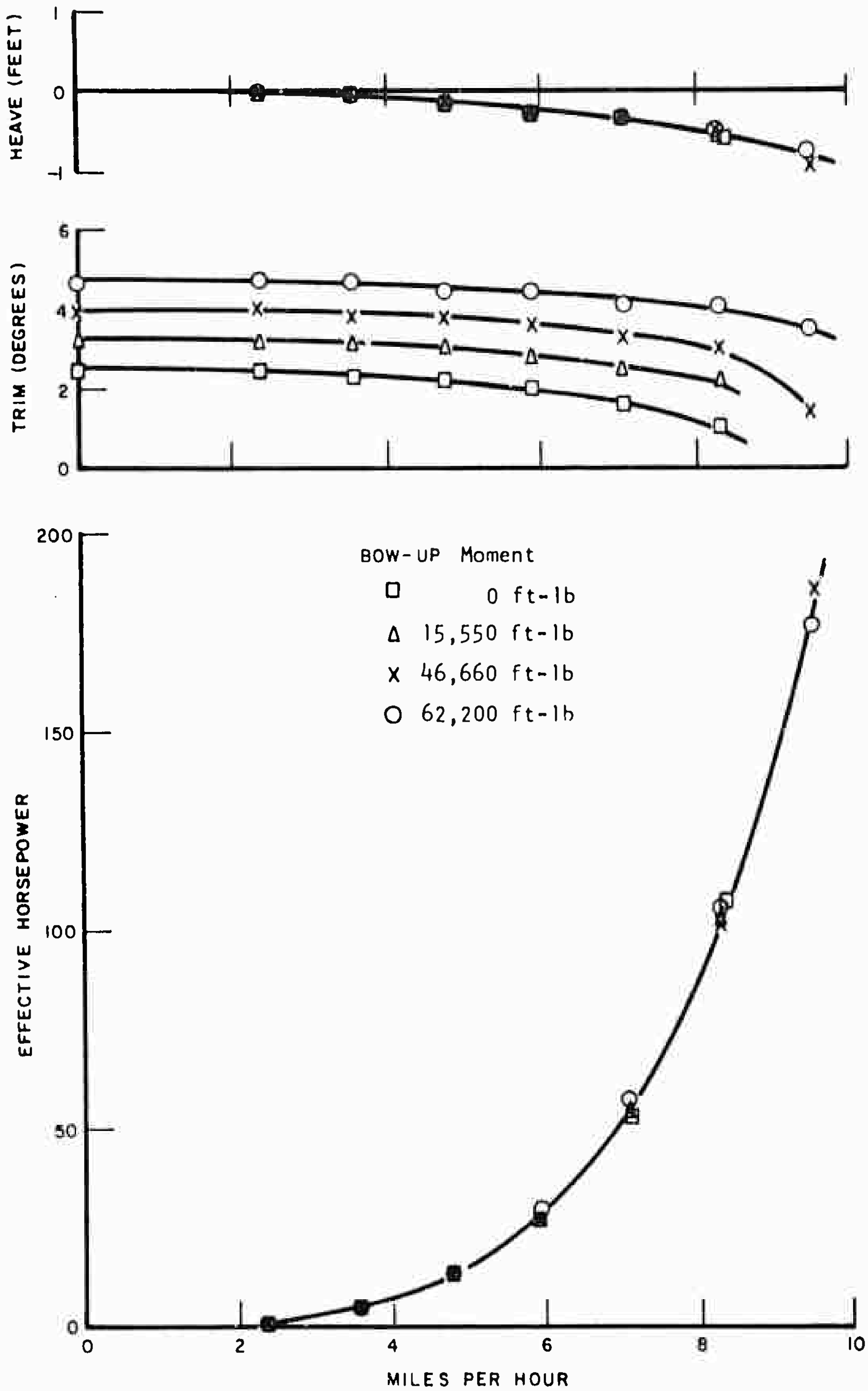


FIGURE 6. EFFECTS OF APPLIED MOMENT AT EMPTY CONDITION

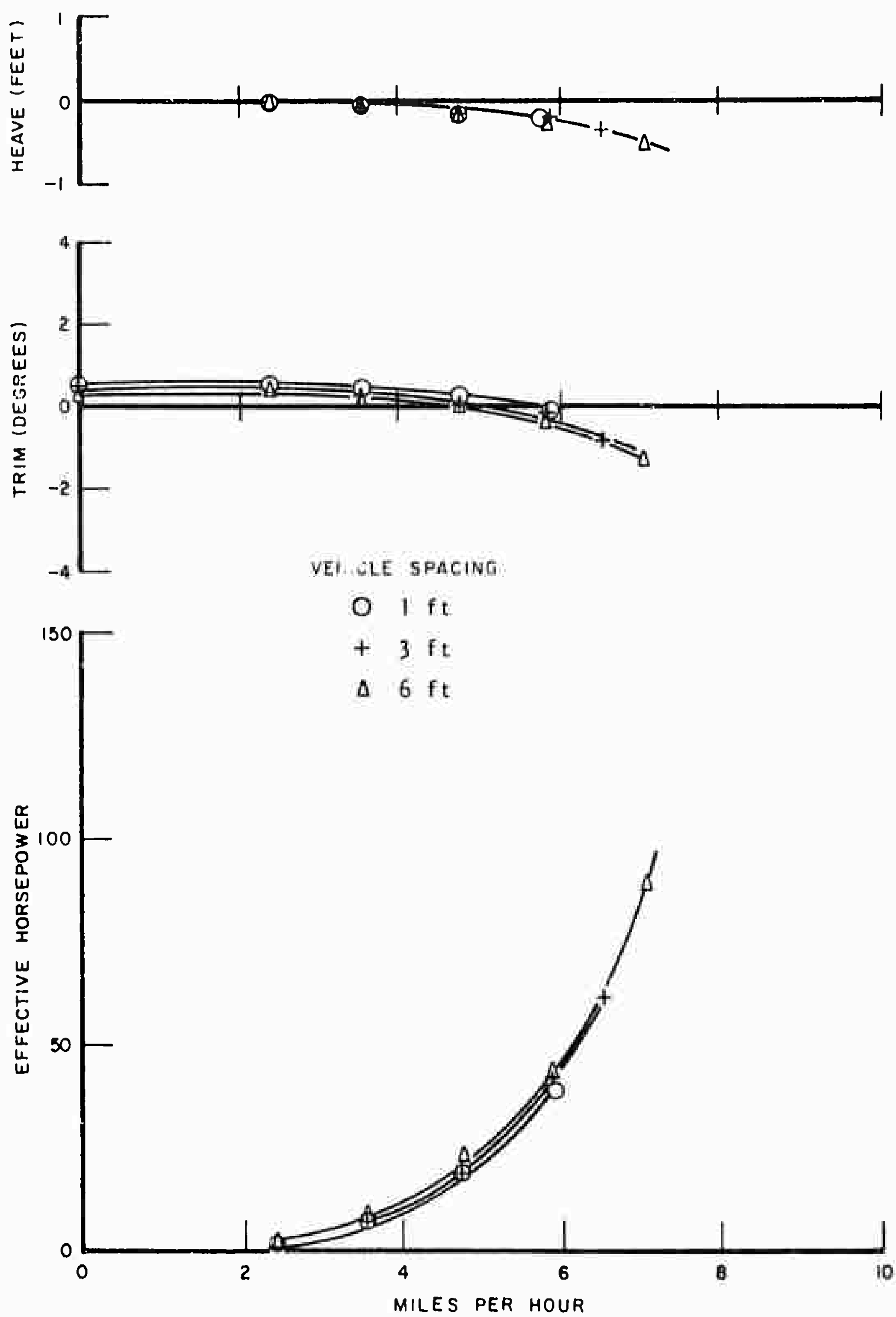


FIGURE 7. EFFECTS OF CONNECTING-LINK LENGTH FOR TWO VEHICLES IN TANDEM AT COMBAT LOAD

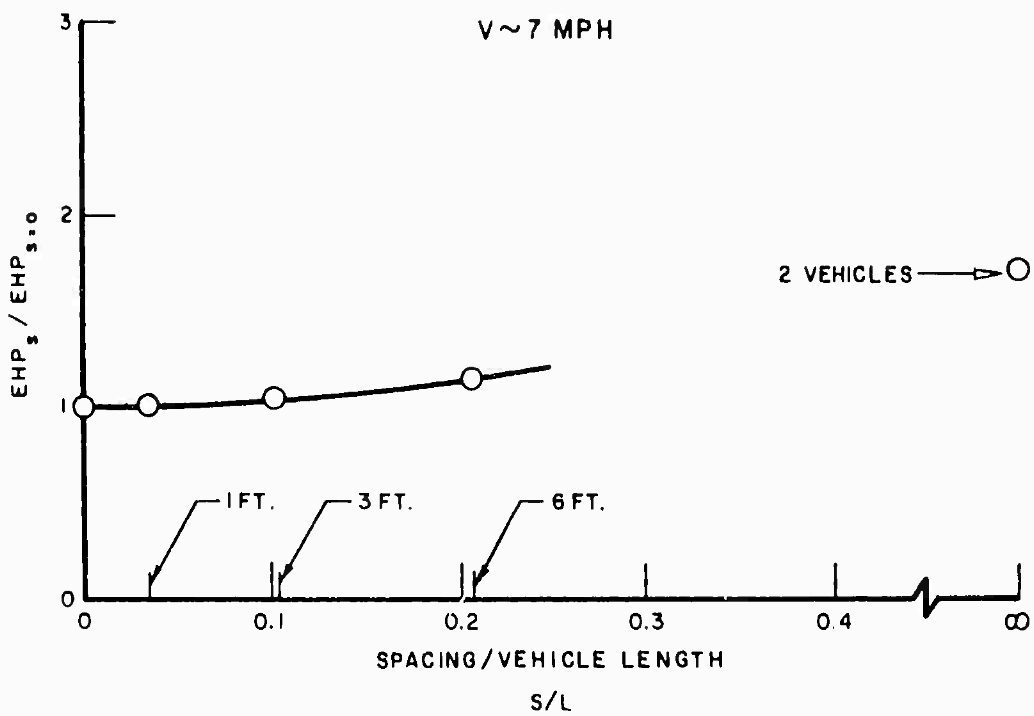


FIGURE 8. EFFECT OF VEHICLE SPACING ON EHP FOR TWO VEHICLES IN TANDEM AT COMBAT LOAD

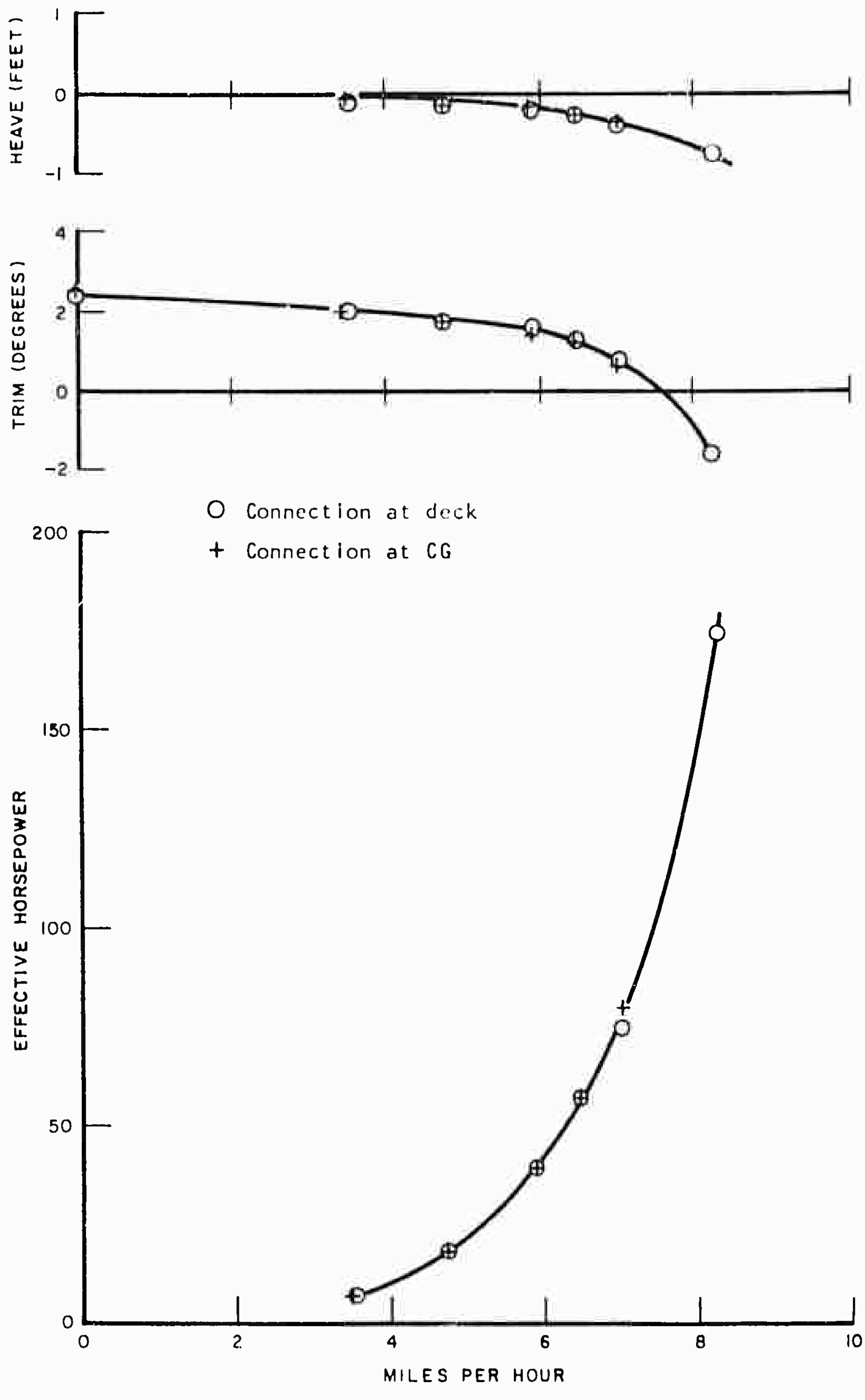


FIGURE 9. EFFECT OF INTER-VEHICLE CONNECTION HEIGHT FOR TWO VEHICLES IN TANDEM AT COMBAT LOAD

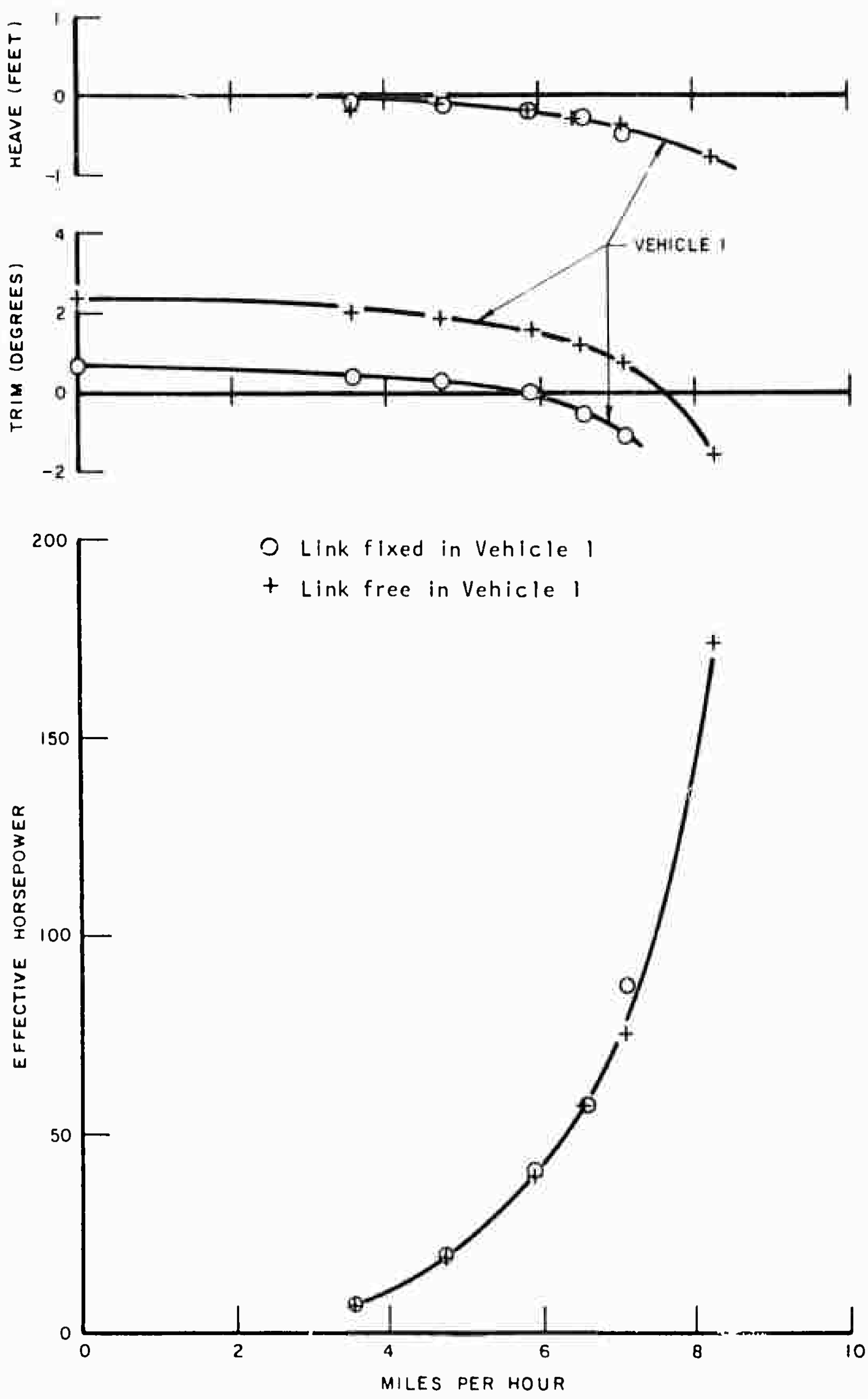


FIGURE 10. EFFECT OF TYPE OF INTER-VEHICLE CONNECTION FOR TWO VEHICLES IN TANDEM AT COMBAT LOAD

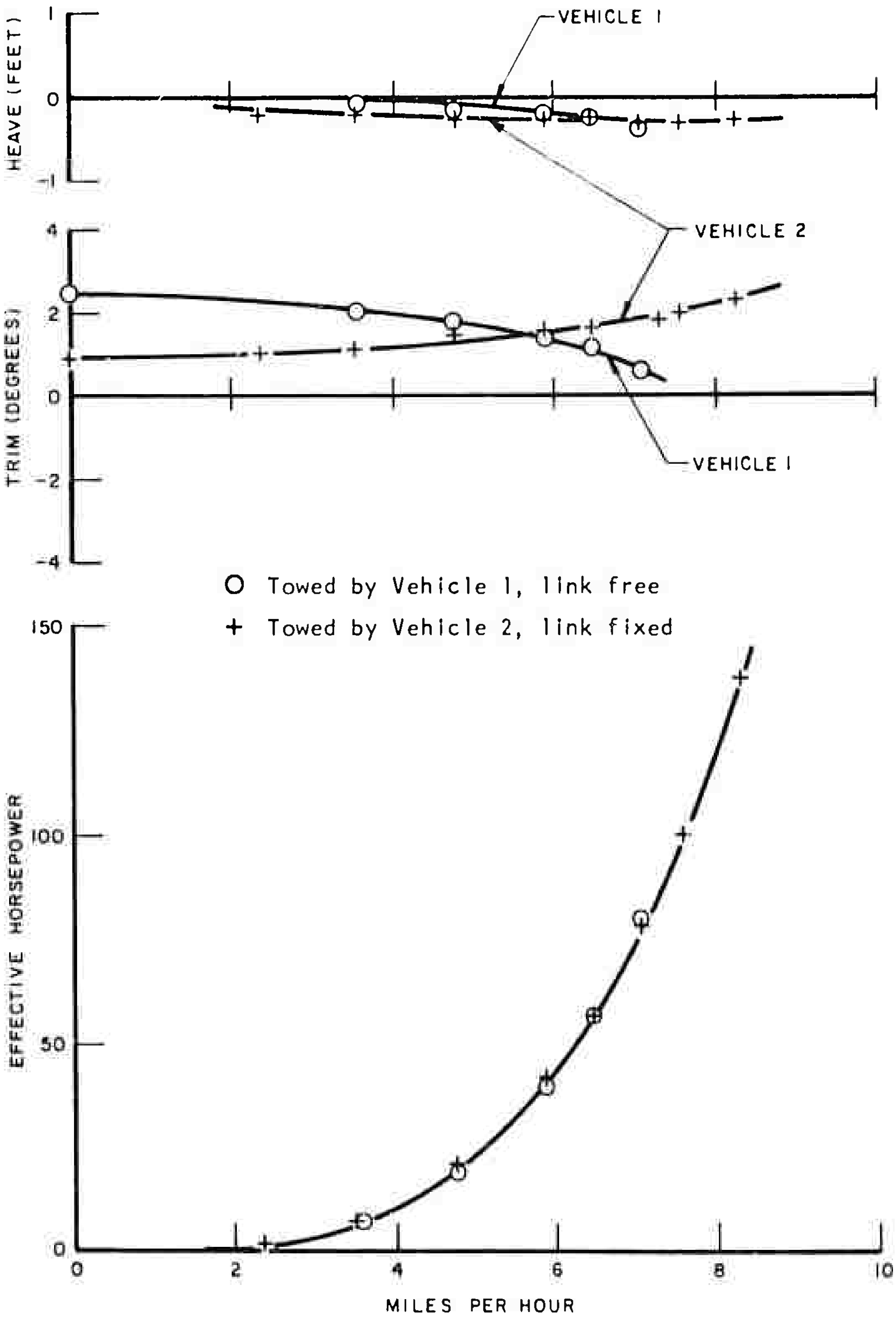


FIGURE 11. EFFECT OF PROPELLING-VEHICLE LOCATION FOR TWO VEHICLES IN TANDEM AT COMBAT LOAD

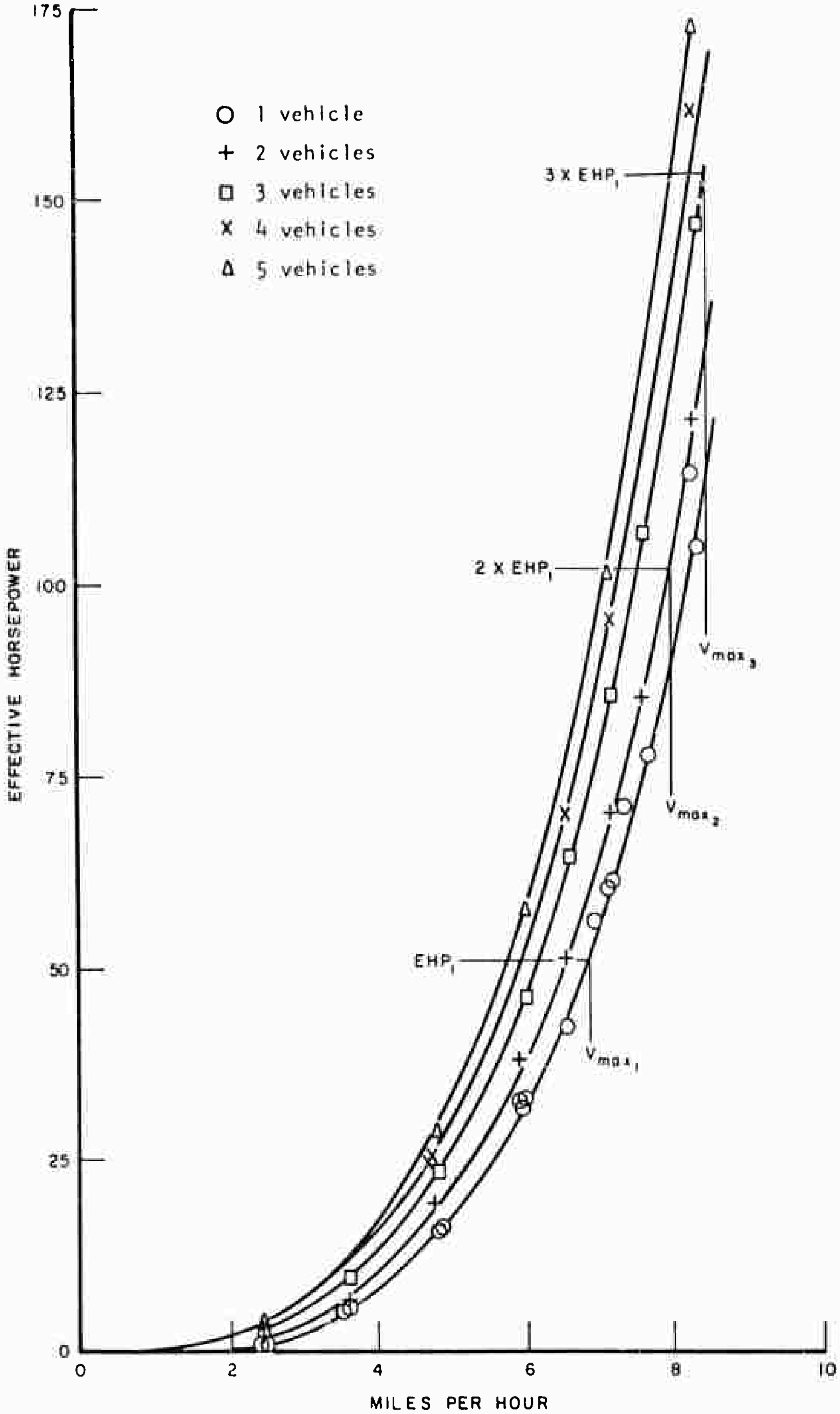


FIGURE 12. TOTAL POWER REQUIRED VERSUS SPEED (COMBAT-LOADED WITH 20-IN. FREEBOARD ON LEAD VEHICLE)

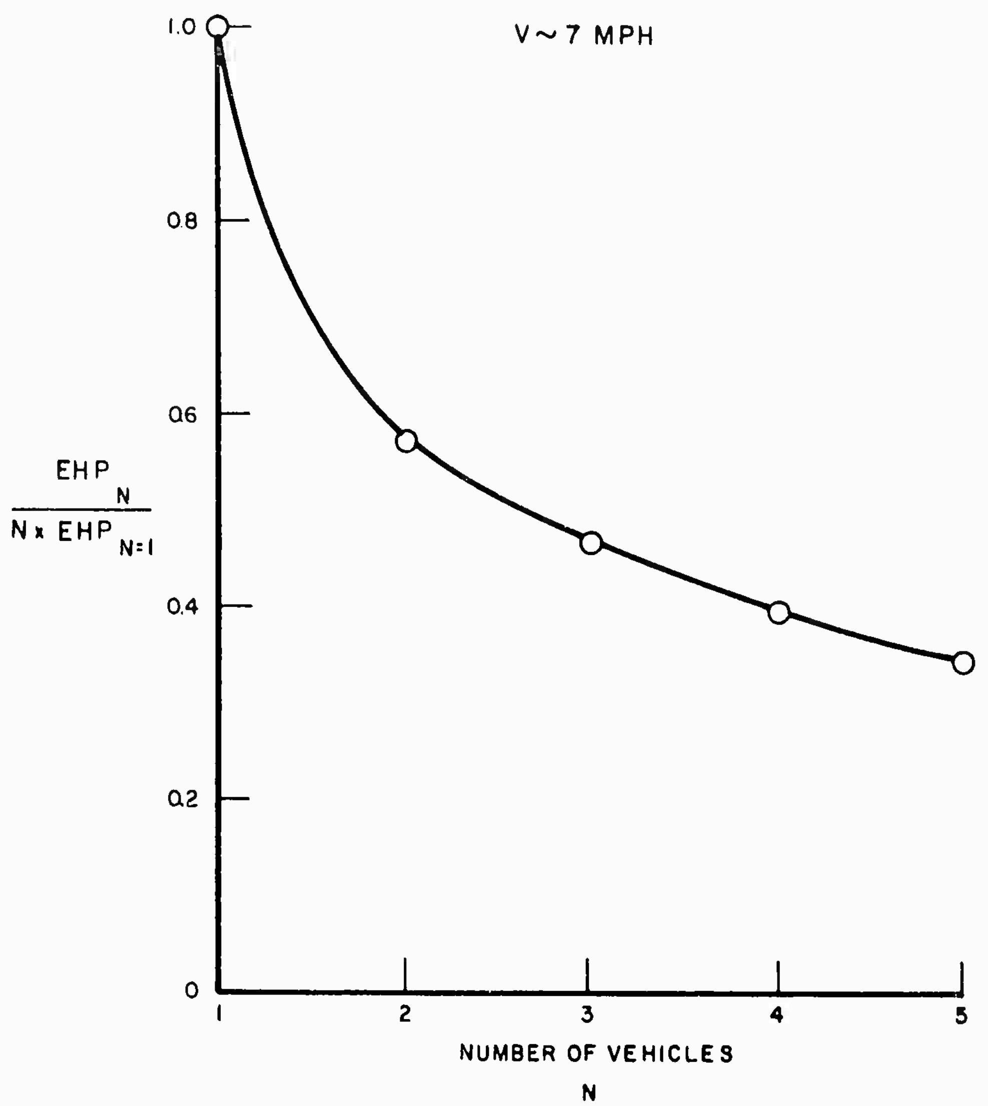


FIGURE 13. AVERAGE POWER REQUIRED PER VEHICLE

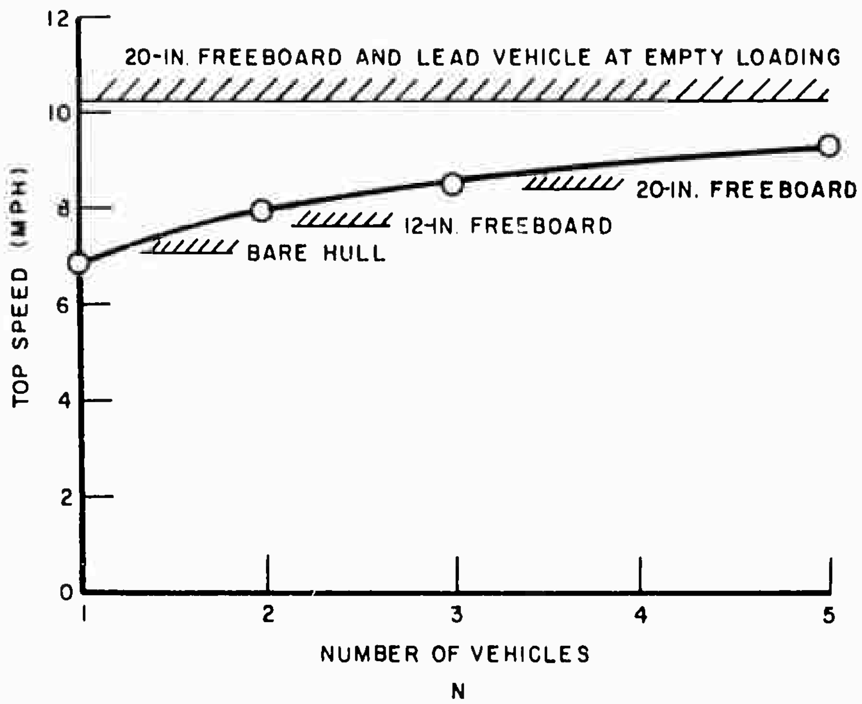


FIGURE 14. PROJECTED TOP SPEED AND SWAMPING LIMITS (FREEBOARD ADDED TO LEAD VEHICLE)

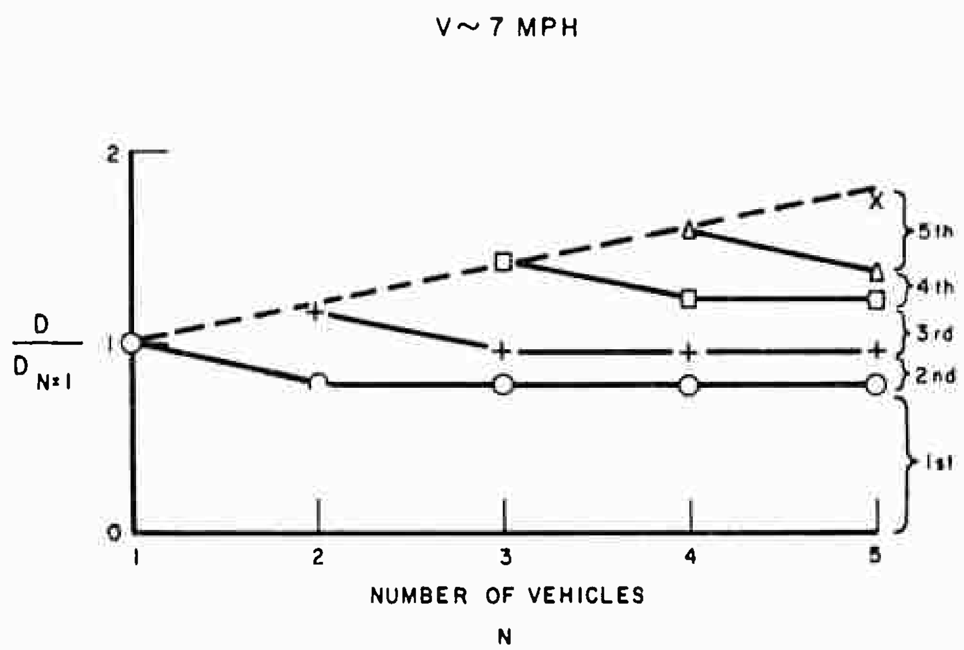


FIGURE 15. DRAG BREAKDOWN BY VEHICLE LOCATION

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13. ABSTRACT

This report describes tests conducted to obtain the hydrodynamic drag characteristics of coupled models of the LVTP-5. Problems of swamping and broaching were also studied, and are discussed.

It was found that the total resistance of a train of five vehicles is less than twice the resistance of a single vehicle. If propulsive efficiency is unaffected by coupling, this represents a potential speed gain of almost 50 percent.

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
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